
METHODS AND RESULTS OF STRIP-MINE RECLAMATION IN GERMANY¹

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All over the world industry is growing rapidly. This growth includes a great increase of surface mining or strip mining, as you call it. In the last 20 years, it has increased much more than underground mining, which, in some of the old industrial countries, is decreasing substantially. A number of factors have contributed to this trend; these include the development of heavy equipment, lower costs, more complete recovery of the coal, and smaller labor requirements. The American strip mines for bituminous coal and the German opencast mines for brown coal (also called lignite) are among the most important examples. This report will present the facts and trends of mining and reclamation in Germany only; it will not at this time make any direct comparison with the situation in Ohio. As you will see, there are very different conditions and solutions, but also very similar trends and problems in the two countries.

Let me take three examples. (1) In both countries the mining industry is forced to go deeper and deeper into the earth, because many of the most favor-

¹Presented at the Strip-mine Symposium held at the Ohio Agricultural Experiment Station on August 13-14, 1962.

²Summer 1962: Post-Doctoral Fellow, Ohio Agricultural Experiment Station, Wooster, Ohio. This opportunity was made possible by a Fulbright Travel Grant-Senior program of U. S. Educational Commission, Bad Godesberg, Germany.

able strata are exhausted; (2) the trend to heavier equipment is evident in both countries; and (3) the oxidation of sulfur to iron sulphate and sulfuric acid causes the same trouble to water supplies.

Hence, it may be useful to know something about the other country. It is, of course, impossible to transplant the whole German reclamation practice to the United States or vice versa; but it is possible, by such comparison, to get new ideas, stimulation, and a better understanding of the whole problem.

ACKNOWLEDGMENTS

I appreciate the three-month leave of absence from the Federal Research Organization for Forestry and Forest Products at Reinbek, Germany. I am also grateful for the congenial conditions for my research in Ohio and the financial support from a Fulbright Travel Grant.

During the summer of 1962 an opportunity was available to inspect strip-mine spoils in Ohio, Pennsylvania, West Virginia, Kentucky, Tennessee, and Illinois. This made possible a valuable exchange of ideas with many scientists and engineers as a basis for the preparation of this paper. I acknowledge the interesting guidance and personal assistance from all people involved. I am especially indebted to Dr. M. P. Koller, Consulting Forester, Ohio Power Company, for helpful advice and the preparation of many charts, and to Dr. R. H. Eckelberry, Professor Emeritus, The Ohio State University, for editorial assistance.

COAL-MINING AREAS OF GERMANY

Germany as it existed in 1937 is now separated into three major parts (fig. 1).

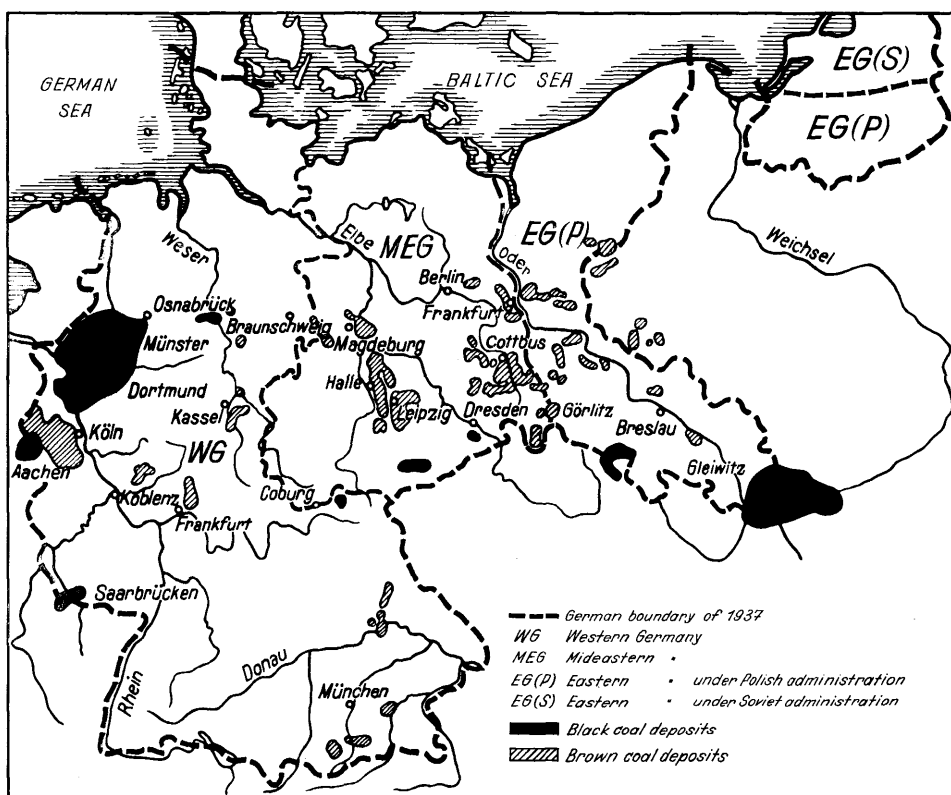


FIGURE 1. Distribution of bituminous and brown-coal deposits of Germany within the borders of 1937 (Pieper, 1962).

The part east of the Oder and Neisse rivers has been under Polish (P) and Soviet (S) administration since the end of World War II. The large deposits of bituminous coal in Upper Silesia belong to the Polish part. There we find underground mining only. Strip-mining of brown coal is restricted to small areas. We shall not consider them in this paper.

Mideastern Germany (MEG) is situated between the Oder and Neisse rivers on the east and the Elbe and the mountains of Thuringia on the west. Your newspapers call it East Germany. Except for West Berlin, it is the former Soviet occupation zone. Its 17 million inhabitants have hardly any bituminous coal strata or oil deposits at their disposal: hence brown coal is their only important natural source of energy. It provides more than 80 per cent of all the energy used in the country. The yearly output had reached 225 million tons in 1960 (Pieper, 1962). The most famous mining areas are the Lausitz around Cottbus and the districts of Halle and Leipzig.

West Germany (WG) is the largest part of the old country; about 53 million Germans live there. The famous bituminous and hard-coal layers of the Ruhr basin, Aachen, and the Saar River are still a good basis of energy, notwithstanding growing oil imports. Their annual output reached 142 million tons in 1960 (Europ. Gemeinsh., 1962). But deep mining for hard coal, at an average depth of 2,500 ft, is expensive and the big power plants are demanding cheaper energy sources. Hence, brown-coal mining is also important for West Germany. In 1960, more than 96 million tons of this material had been hauled from its open-cast mines (Pieper, 1962). This is less than half of the output of Mideastern Germany, which has no bituminous coal. But we must remember that one ton of brown coal is an equivalent for only 0.2186 ton of hard coal. For our purposes, the only important brown-coal mining district of Western Germany is the Rhineland (also called the mining district of Cologne); all other districts together produce less than 15 per cent of the total.

RECLAMATION AN INTEGRATED PART OF STRIP MINING

In order to expose the coal, opencast mines in Germany have to ruin the existing landscape; this is true over the whole world. But it is now clear to people in Germany that destruction must not be the last step: it must be followed by some kind of reclamation. In place of the lost cropland, forests, and villages, new ones must be established. This belief has led to reclamation laws in both Western and Mideastern Germany (Gesetz . . . , 1950, Verordnung . . . , 1951 . . . , 1958).

Reclamation means the restoration of a fertile and pleasing landscape, either for the economic return from agriculture and forestry or for the sake of recreation. Figure 2 shows that reclamation is an integrated part of mining in a German brown-coal mine. Before mining (a), forests, cropland, meadows, and villages occupy the surface; the coal is covered by overburden and lies far below the ground-water level.

The first step in mining is to lower the water table (b). Then the excavators start to open the pit (c). In this initial stage, the spoil material has to be dumped on the non-coal-bearing land outside the pit, since there is no space within it. The affected land cannot yet be reclaimed.

Conditions for reclamation are better after the first strips of coal are mined, because the pit can be refilled with fresh spoil material (d). Then the spoil placed outside the pit can be covered with good material or at least be brought to a form that minimizes erosion. The spoil banks inside the pit also can be covered or graded. When the coal field is exhausted, the pumps are removed. The ground water will then rise and fill the open pit. Grading the bottom and adjusting the slopes have to be done before the water prevents them (e). The revegetation is shown as one action (f), but in reality it had started long before on the parts

first strip mined. Agriculture can be resumed on those areas where productive soil has been brought to the surface, whereas other parts have to be afforested. Some years later a new landscape has developed, having new features, but being as productive and beautiful as before (g).

SCHEMATIC PROCEDURE OF BROWN COAL SURFACE-MINING TO FINISHED RECLAMATION, IN GERMANY.

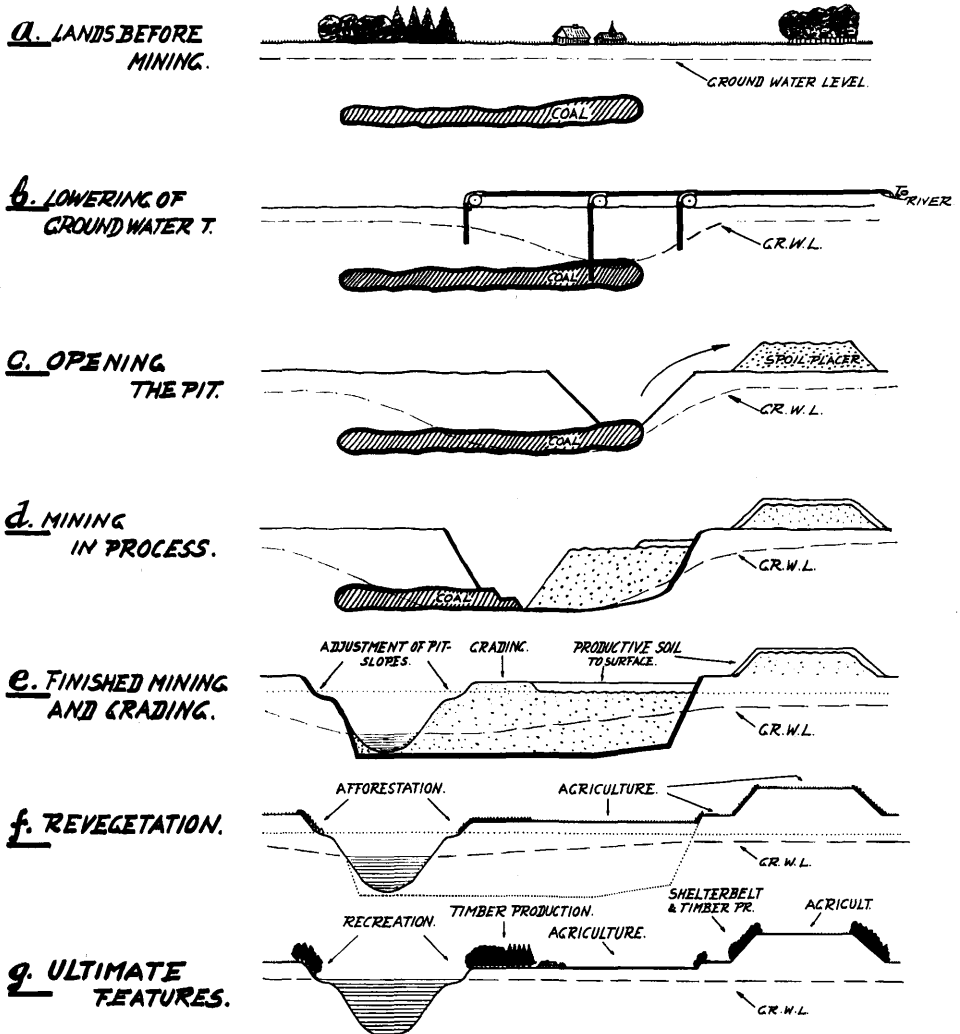


FIGURE 2. The history of a man-made landscape. Schematic procedure of brown-coal surface mining to finished reclamation in Germany.

But let us note the different stages of reclamation. We find four:

- (1) Pre-planning of future land-use and type of reclamation
- (2) Soil management and restoration of the surface by mining equipment
- (3) Afforestation or agricultural cultivation of the new land
- (4) Permanent use for agriculture, forestry, or recreation.

The success of the reclamation must be judged by the benefits in this period of permanent use, rather than by the yield of pioneer crops. The permanent productivity of the soil and the industrial capacity constitute the economic potential of a given area. The next step is to identify the factors which affect this potential.

So far as I can see, within a given climate there are these possible reasons for success or failure:

- (1) The geological structure of the deposit, chiefly the value of the different strata of the overburden for plant growth. This determines the agricultural value of the area. I called it "Kulturwert der Abraumschichten" in 1952. We shall deal with it later.
- (2) The methods of mining operation, especially the disposal of the overburden and the restoration of the surface
- (3) The methods of improvement for agriculture and forestry
- (4) The intensity of further land management (Knabe, 1957).

Only the first factor is a given one; all the others depend on the will and foresightedness of the inhabitants, which are manifested by their laws, the voluntary efforts of mining operators, and the public interest in the problem.

THE AGRICULTURAL VALUE OF THE OVERBURDEN

The geological character of the land is the most important factor affecting reclamation. Only deposits which can be mined profitably can be considered. The costs of mining must not exceed the income from selling the raw materials. The more profitable the mining of any deposit, the more money is available for reclamation. Mine operators with high costs and low profits will not willingly pay anything for reclamation. The decisive significance of the geological composition, however, is determined by the qualities of the different strata above the coal.

In the beginning of surface mining in Germany, the industry did not consider these qualities. Overburden was overburden, waste material to be disposed of at the least expense. The different strata were mixed or not, as most convenient. Later on, it was observed that this material showed great differences. On one bank wheat and sugar beets could be grown again; on the other there was not a single plant 20 years after dumping the spoil material. Farmers who would not sell their land but only lease it for mining demanded that the old topsoil be spread over the banks again, and mining operators yielded to this demand. The first reclamation amendments to the mining law were enacted in 1929 (Oberbergamt Bonn, 1929). In 1940, a new law required all good topsoil with a depth of more than 20 inches to be separated and spread over the banks, and prohibited placing toxic material on the surface (Reichswirtschaftsminister, 1940).

After World War II, there was demand only for coal, and reclamation was ignored. But beginning in 1950, reclamation efforts increased more and more. New laws with more precise requirements were enacted in both Western and Mideastern Germany. Simultaneously the need for scientific investigations became clear; at that time, I began my reclamation studies in Berlin.

It became obvious that laws for separating fertile and toxic spoil material were not enough: we needed to know which strata are which. The old geological maps had not considered this. Hence, I devised a system of five classes, based upon the agricultural value of the overburden and the necessity for different management during mining (Knabe, 1952, 1955). Next, I tried to define the qualities of a

stratum that determine its agricultural value (Knabe, 1957, 1959a). I shall describe these classes in a simplified manner.

TABLE 1
Classification of overburden layers and their management for reclamation

| Value class | Usability for crops | Examples | Management in mining process |
|-------------|--|---|--|
| I & II or A | Good for Agriculture | Loess, good loams, calcareous clays | Separate excavating, separate transportation, dumping on the surface of the bank |
| III or F | Usable for Forestry | Nontoxic sands, loams, clays | Management like A, if A is absent |
| IV or St | Sterile or barren, can be revegetated but will bring no crop | Quartz gravel very poor sands | Preferably not to be brought to the surface |
| V or T | Toxic, with ingredients that will poison; also mixtures with other layers. | Layers containing Pyrite or other toxic ingredients | Not to be brought to the surface; must be covered by fertile material. |

It is obvious that within these classes there may be great differences: between a loess and stony glacial till, for example. Hence, these classes are only a help for the mining engineer; the specialist has to look for the best stratum or mixture for a particular area. Some typical examples will be helpful.

The upper row of figure 3 shows simplified profiles of five different types of overburden in German brown-coal mines. Figure 4 shows the very complicated conditions which sometimes occur. The agricultural value of the different layers is marked in figure 3 by the pattern and the symbols A, F, St, and T, and the coal by C. The scale is relative only; the relation between coal and overburden is shown, but not their absolute heights. The lower row shows schematic profiles of the spoil banks after mining, with reference to their value. These profiles are the results of different mining methods.

Let us now look at some examples.

(1) Type F

Above a coal seam of 70 to 300 ft in the older part of the brown-coal area of Cologne (the "Ville"), there was only a stratum of 30 to 100 ft of sandy gravel covered by a thin layer of loess, which had been degraded by stagnant water. This is suitable only for forestry. No matter whether the mine operator mixes or separates the strata, the soil will be suitable only for wood production and recreation. We may call it type F.

(2) Type A

F

St

In the areas outside the Ville, the coal seams lie much deeper. There we find 6 to 60 ft of fertile loess (class A) above the same sandy gravel, as in the preceding example, and below it infertile sand, clay, and gravel of the Tertiary to a total depth of 300 to 1000 ft. These layers are not at all poisoned. We call this type A

F

St

If we separate the loess during excavation and transportation and cover the graded banks with a layer of 4 ft of loess, we shall get a highly productive

SCHEMATIC GEOLOGICAL PROFILES ***OF DIFFERENT GERMAN BROWN COAL AREAS.***

DEMONSTRATION OF CULTIVATION VALUES & THEIR LOCATION BEFORE & AFTER MINING.

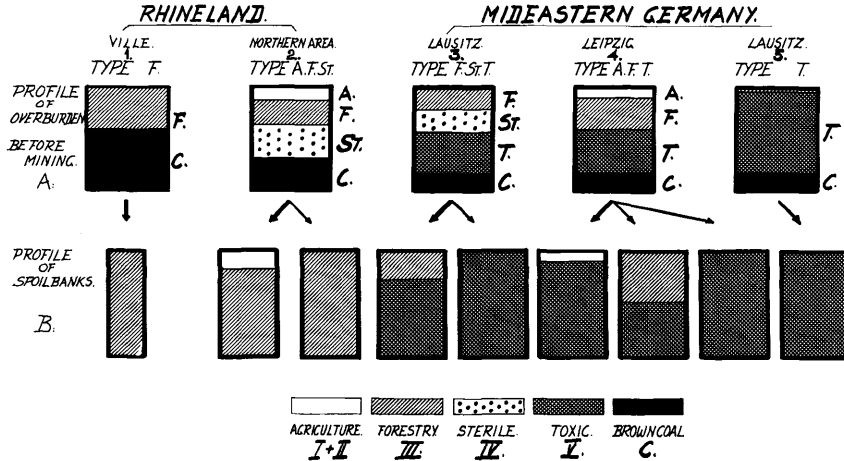


FIGURE 3. The agricultural value of undisturbed overburden and spoil banks in some German brown-coal areas. Arrows indicate the results of management with different intensities: (a) random mixture, (b) productive-soil management, (c) topsoil management.

LAND PROFILE OF STRIPMINE GARS DORF.

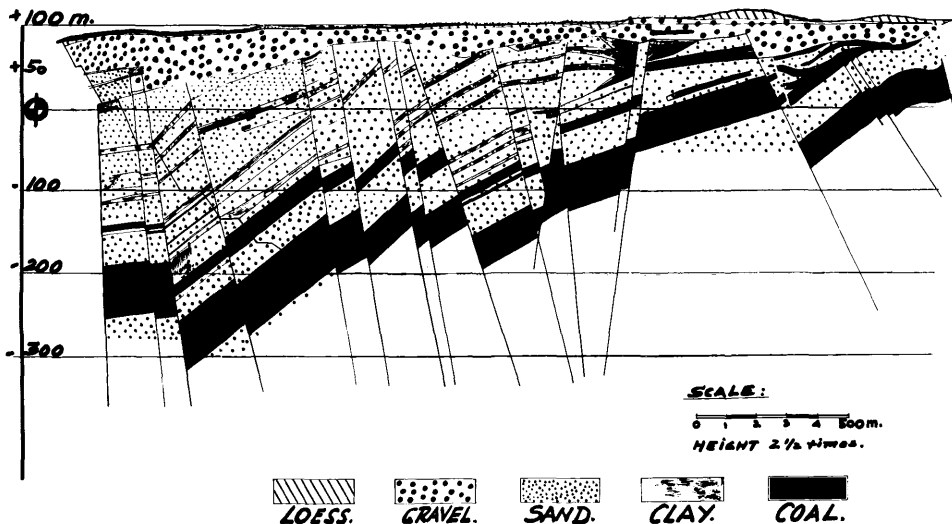


FIGURE 4. Geologic profile of opencast mine at Garsdorf, Rhineland. Note high layers of overburden and many faults, which can be successfully mined by bucket-wheel excavator only (Pieper, 1962). 1 m = 3.3 ft.

agricultural area. If we mix all the overburden together, we shall get a material of class F, usable only for forestry. In practice, only Pleistocene material, that is a mixture of loess and gravel, is used for forestry, since it is more fertile than a mixture of all the layers.

(3) Type F

StT

In the Lausitz, we find also Type F but mostly type F. This means that

StT

fertile layers of A are absent. The upper strata are sands of the Pleistocene Epoch; the lower are poor gravel of the same age, or poisoned sands, loams, and clays of the Tertiary, all of which contain more or less pyrite. Worst of all is the so-called *Kohlenletten*, a dark soft shale, which also contains much pyrite, but worse, becomes water-repellent after a short period of weathering, so that the plants cannot get water and the sulfuric acid cannot be washed out. If all these layers are mixed together they produce a poisonous material which for many years will prevent any plant growth. In this case, the soil has been ruined. But one can save a forest soil if he separates the better part of the overburden and puts it on the surface of the spoil bank.

(4) Type A

F

T

The more complicated case, $\begin{matrix} A \\ F \\ T \end{matrix}$, is found in the outside zone of the Lausitz

and also south of Leipzig. Here fertile loams or calcareous clays of class A overlie sandy gravel of class F and poisoned Tertiary material of class T. Agriculture can be restored only if one separates the upper layer. A mixture with the next stratum will produce a forest soil, whereas a mixture of all the overburden will usually result in a toxic material.

(5) Type T

Conditions which are still worse than any type mentioned above are sometimes found: all layers above the coal are toxic. We may call it type T. Fortunately, because the surface is largely leached out, it is quite rare. But I can mention two examples. If pyritic material is covered by water or peat it can neither oxidize nor leach. Also toxic pre-law spoil banks which have to be displaced to strip a deeper coal seam offer no fertile layers to be separated. In these cases the new spoil banks will be toxic again. If there is no chance to bury the toxic material by fertile layers from an adjacent mine, the mining industry can do nothing.

There is not time enough to explain the methods of soil investigation which are needed for classification, but the interested soil scientist can use available publications (Knabe, 1959a; Kopp, 1960; Koller-Knabe, 1962). I wish at this point only to mention one basic principle concerning this matter. A brown-coal mine with an annual output of 1-20 million tons must be thoroughly planned many years ahead. A desire for reclamation cannot be fulfilled if, before starting the mine, one has not investigated and ascertained the agricultural value of the overburden. This is done by studying the samples of overburden collected from the boreholes made to test the depth and quality of the coal. I started my first investigations of this kind in 1952. Some years later we developed a system of exact analyses in order to find out the needed information at moderate cost. While the simple tests could be performed on nearly every sample, the more expensive investigations were restricted to a few boreholes (Knabe, 1959a, b). Kopp (1960) studied the matter further. He investigated nearly the entire Lausitz mining district and found higher correlation between geological strata and

agricultural value than we did on a few mines. So he could reduce the number of samples by taking account of the strata involved.

The character of the deposit affects reclamation in other ways. In many cases, it has influenced the kind of mining and the equipment used. The big conveyor bridges have been developed for the relatively regular coal seams of the Lausitz, but are almost unknown in the Rhineland.

Let us now consider systematically the different systems of opencast mining in Germany and their effects on reclamation.

DEVELOPMENT OF MINING EQUIPMENT AND ITS EFFECTS ON RECLAMATION

The different techniques represented by American and German strip-mine equipment is an astonishing fact. Up to the end of World War II both sides were more or less isolated from each other and hardly recognized the development abroad.

In DEBRIV (1960) we find a good report on the technical development in Germany. The unknown author shows four stages in which the mining industry developed from manual operations to partially, and then fully, mechanized ones (table 2). The most recent mass-production operation, with new machinery, made possible a daily output from a single mine up to 100,000 tons of coal, or 30 million tons a year.

TABLE 2
*Stages of development in German lignite opencast mines**

| Period | Name of stage | Average daily output of coal in tons from one operation |
|------------|--------------------------------|---|
| Until 1885 | Manual Operation | 1,000- 3,000 |
| 1885-1925 | Partially Mechanized Operation | 5,000- 10,000 |
| 1925-1955 | Fully Mechanized Operation | Up to- 40,000 |
| 1955- | Mass Production | 50,000-100,000 |

*DEBRIV 1960, page 47.

Using the first excavators, brown-coal production by strip mining increased from 30 to 70 per cent in the 20 years between 1890 and 1910, and underground mining decreased by the same amount. Today underground mining for brown coal has almost disappeared. We find spoil banks and open pits instead of the sinkholes which were so common in the old mining districts.

It is interesting to note that, from the early beginning of opencast mining in the nineteenth century, the different phases of overburden disposal have been separated. Excavators dug up the overburden and trains—later conveyor belts—transported it to the banks, where it was tipped or dumped. Thus there are three phases of spoil disposal: excavating, transporting, and dumping. The strip mines of the United States have used only one power shovel or dragline, which excavates, transports, and dumps the overburden all together. The principal reason for this difference may lie in the physical conditions that obtain in Germany; the overburden is loose and therefore easy to cut, but has a tendency to slide; both the coal seams and the overburden are thicker; and water pumping is necessary to prevent flooding of the mine, which, in turn, favors a trend toward larger mines. But the difference in the two countries may be due also to the fact that strip mining began later in the United States, when excavators large enough to do the whole job had been developed.

In 1885, only little bucket-ladder excavators with a cutting depth of 10 to 20

ft were available in Germany. They were not able to take away the whole overburden with one cut. Hence, the excavation side of an opencast mine was subdivided into several cuts, separated from each other by plane benches on which the excavators moved. Small wooden hopper cars with a capacity of about one, later on 3 to 5 cubic yards, transported the loose material on rails to the dump side of the mine and side-dumped the material. In order to prevent sliding of the loose material, the piles had to be kept low. So one found on the dump side a series of low terraces similar to those on the excavation side. In order to avoid excessive railroad grades, the upper layers of the overburden were usually taken to the upper dumps, and the deeper toxic ones to the lower dumps. Although the mine operator of that time paid no special attention to reclamation, this old practice resulted in banks having on the surface no toxic substance, but rather a mixture of upper-cut material suitable for forestry.

After World War I, mining equipment increased in size. The excavators were able to take away 50 to 130 ft with one cut; hence mixing of fertile and toxic material became more frequent and resulted in the enactment of laws against it.

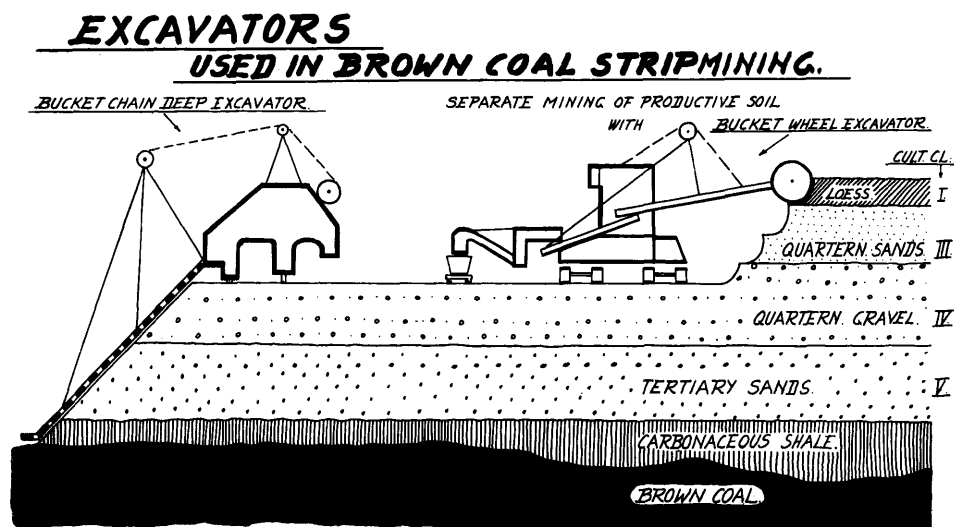


FIGURE 5. Older and newer types of excavators in opencast mine of Mideastern Germany. Bucket-wheel excavator can separate fertile loess for covering the spoil banks (Knabe, 1959a).

From 1885 until World War II, bucket-ladder or bucket-chain excavators predominated (fig. 5, 8A). This type was developed from dredgers working in the rivers and on the seacoast. If it was cutting above haul level, it was able to cut no selective horizontal layers, and scarcely any, if it was cutting below this level. The most useful type for separating the upper layers was the slewable bucket-ladder excavator, available since 1922 (fig. 6). This type could cut in either direction, but that was useful only if its haul level was above the toxic zone. The use of the bucket-ladder excavator has decreased since World War II because the bucket-wheel excavator, since its first successful application in 1933, has proved to be, in many ways, the better type (fig. 5, 8B, 8C). Its bucket wheel can selectively mine coal and overburden, or different kinds of overburden, the only condition being that these layers should be not too thin in comparison to the diameter of the wheel. This capability for selective mining is very important for deposits with faults (fig. 4). You can find more information concerning German

bucket-wheel excavators by the prospectuses of Krupp and Lauchhammer, and Linden (1957). Separating of a fertile layer is possible, if a bucket-wheel excavator is used in the first cut; this is typical of block operations in Fulton County, Illinois (N.N., 1960). Where such equipment is not available, German practice may also use bucket-ladder excavators, or small power shovels, and small draglines, but these are only expedients.

A separate excavation of fertile soil means nothing unless separate transportation and spreading can be arranged. In a mine with rail haulage for overburden, a separate rail system from the excavator to the top of the spoil bank is needed. Then trains hauling the good material use it and dump their material on top (fig. 8D).

The separate transportation of fertile soil became difficult after 1929, when a new system, the conveyor-belt bridge, became more prevalent, especially in the Lausitz mining district (fig. 6). This was a mobile steel bridge which crossed the mine from the excavators to the spoil side. It had an endless conveyor belt, which took the spoil material from the excavators, transported it across the bare coal seam and the safety strip, and dumped it on the bank. If the material came from one or more excavators, all strata were mixed. Since the costs were quite

SCHEME **OF A CONVEYOR BRIDGE WITH TWO SIDE SUPPORTS.**

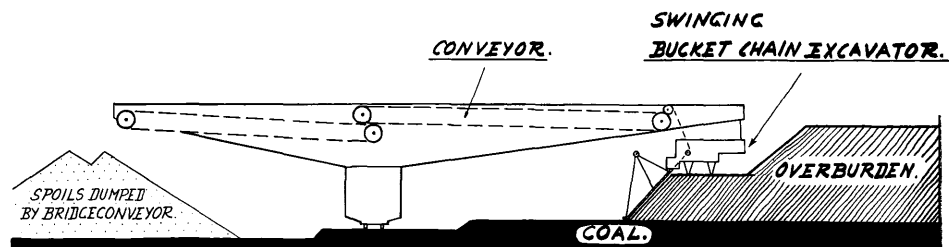


FIGURE 6. Transportation and dumping of spoil material by one plant, a conveyor bridge. Cheapest way of spoil disposal in regular brown-coal seams up to a height of overburden of about 200 ft. (Knabe, 1959a).

low, this system was very economical for the mining industry, but it was bad for agriculture and forestry, since it resulted in a poisoned "moon landscape" (fig. 9G). This was due, not alone to the mixing of the overburden, but also to the rolling surface and the lowering of the surface by excavation of the thick coal seam. The completion of an operation and removal of the pumps often was followed by flooding of those areas having a high water table.

An attempt was made to solve the problem by separate rail haulage, but that proved to be very expensive. Just at the right time, a new transport system, shiftable conveyor belts, was developed in Bavaria and the Rhineland. The belts are mounted on sleepers or steel sleds which are readily movable. The conveyor belts run round the mine from the excavator to the spoil dump. Each of the giant excavators may have a separate conveyor belt (fig. 7, 8B). The separate transportation of the fertile overburden does not require an additional belt, but only separate time—the time when the excavator is cutting the good soil.

The technique of conveyor belts is still under development. In figure 7 you see a belt-conveyor system for hauling the coal and overburden. Each of the many terraces has a height of about 100 to 150 ft.

The way the dumping is done is important. The first improvement over side dumping from the rail trucks was the introduction of rail-mounted plowing machines, which pushed the side-dumped spoil farther away from the rail and increased the stability of the spoil slope against slides. Since 1915 a new machine, the spoil-disposal spreader or stacker, has made possible better operation. It excavates the spoil from the receiving ditch behind the track and, by means of a belt-conveyor boom, dumps it into the worked-out pit far to the other side. Thus no sliding can endanger the spreader. The largest of these modern spreading plants has a daily capacity of about 250,000 cubic yards of virgin overburden. Their booms have a length of about 300 ft and allow a maximum dumping height of 111 ft above truck level and a much greater depth below. In mines with this kind of

PERSPECTIVE OF **CONTINUOUS CONVEYOR OPERATION** **FROM EXCAVATION TO SPOIL DEPOSITION.**

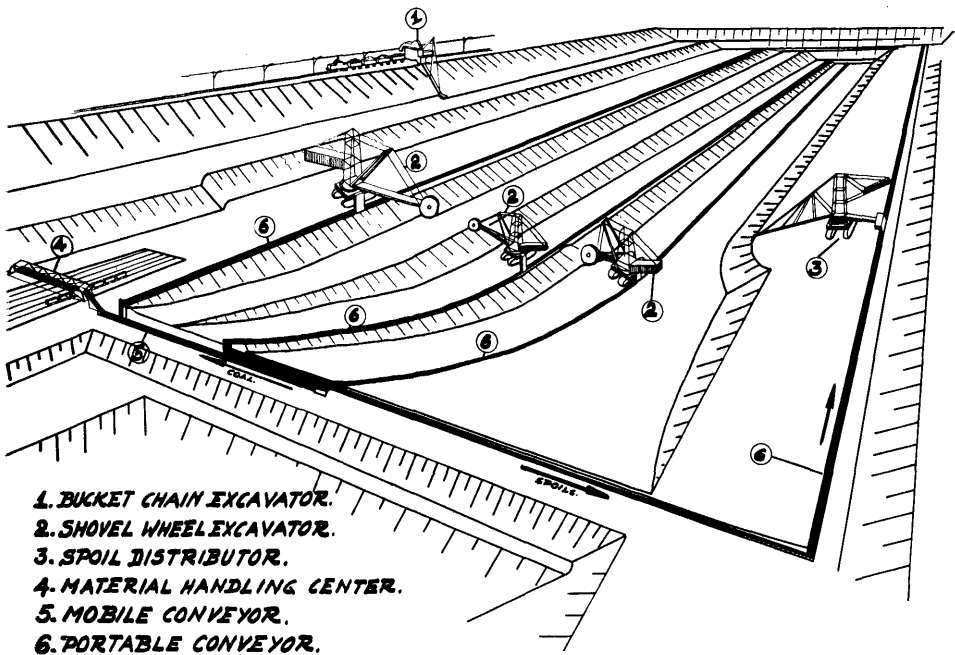


FIGURE 7. Perspective of continuous conveyor operation from excavation to deposition in a brown-coal mine of Western Germany. Note special handling of the first cut for covering the banks.

spoil haulage, the spreading plants do not have to dig up the spoil from the receiving ditch, but get it directly from the conveyor belt (fig. 8E).

Since 1952, auxiliary mining equipment, including bulldozers, Tournadozers, graders, scoopers, small specialized excavators, and mobile cranes, has been strongly influenced by American equipment and in part consists of machines imported from America. The smaller size of these makes them useful for reclamation also, especially for spreading heaps of topsoil and for grading. Motor trucks are also

used for transportation of loess for shorter distances. But you know these types, and I want to tell you another story; the use of water as a transporting agent for fertile soil.

Already at the time of World War I, mine operators found out that water was a very cheap means for transporting sand. The dry sand was dumped down a slope leading to a hole directly above the outlet of some water pipes. The flowing water took the sand away and then could be pumped back from the bottom of the hole for a new cycle. If you have an open pit with slopes too steep for use as a recreation area, you can make gentle slopes by using such a *Spuelkippe*. This method of spoil disposal, however, disappeared when the large spreading plants became common. But that is not the interesting story. An engineer of the *Deutsche Bauernsiedlung* in the Rhineland wondered if it were possible to transport loess by means of pipes. Colleagues laughed at him, but he made a trial and succeeded (Naujocks, 1962). It was found that transportation of loess mixed with water in the ratio 1:2 could be pumped in pipes at half the cost of other means of transportation (fig. 8F). This year the leading mining company *Rheinische Braunkohlenwerke AG* will start a large-scale trial to test his results.

AGRICULTURAL RECLAMATION

The establishment of new agricultural fields presents no problem when the mining industry has met the requirements of agriculture. These are:

- (1) The surface of the land must lie above ground-water level. It is important to note that this level rises after the mining is completed.
- (2) Means must be provided for draining precipitates.
- (3) An arable plane surface is needed, although gentle slopes may be usable for dairy production.
- (4) The top cover of the bank must consist of a kind of overburden which will become fertile soil and produce good crops, and which contains no rocks dangerous to agricultural equipment.
- (5) The arable banks must have access ways and lie not too far from the farm buildings.

The technique of farming on new banks of this type seems, at first sight, to be not too different from the usual ways. Naujocks, for example, reports (1962) the following yields in the first year on a fresh spoil bank carefully covered with 4 ft of loess:

| | | |
|--------------------|--------------------------|-------------------------|
| Wheat | 44.00 dz/ha ³ | (=64.1 bushel/acre) |
| Rye | 37.60 dz/ha | (=59.2 bushel/acre) |
| Barley-oat-mixture | 31.30 dz/ha | (=about 69 bushel/acre) |
| Alfalfa | 3 cuts through August | |

Oestrich (1961) mentions the following yields on loess cover of about 2 ft:

| | | |
|-------------|---------------------------------|------------------------------|
| | Seed | Straw and Chaff |
| Wheat | 32.7 dz/ha (=48.1 bushels/acre) | 44.2 dz/ha (=1.95 tons/acre) |
| | Beets (pure) | Leaves |
| Sugar Beets | 224 dz/ha (=9.88 tons/acre) | 127 dz/ha (=5.6 tons/acre) |

Conversion rates (Bading, 1947)

1 dz = 100 kg = 220.5 lb = 0.11023 short tons

1 ha = 2.47 acre

1 bushel wheat = 60 lb

1 " rye = 56 lb

1 " barley = 48 lb

1 " oats = 32 lb

This would mean that the farmer has free choice of crop (fig. 9H). But there are many problems; even the fertile loess must be handled carefully.

The first danger is *mechanical compaction*. Transportation and grading of the loess should be restricted to dry periods in the summer. Master (1961) has studied

the effects of different ways of loess disposal. Heavy pay-loaders caused the worst compaction (porous-volume 33 to 35 per cent); even the roots of alfalfa did not penetrate these horizons. Transporting loess by train and grading by rail-mounted plowing machines was the best method. Two other methods are intermediate; transportation by motor trucks and grading of the heaps by bulldozers, and still better, the use of trains and spreaders instead of the motor trucks.

Loosening the ground immediately before spreading the loess allows the roots to go deeper into the soil and causes better drainage. If one uses implements which loosen the whole area and not only isolated narrow strips, deep loosening of the loess cover itself also may be helpful. Schulze and Engels (1962), however, in one trial found no good effects on the yield and a relapsing of the loess to a heavier compaction than before. The same authors found a lasting improvement in soil structure, yield, and fertility by growing deep-rooting green-manure plants, sweet clover and alfalfa in particular. Hence, they advocate this biological method of soil improvement.

One of the most interesting findings of these studies was that fresh-graded loess banks are less porous than undisturbed loess soils (porous volume 45 to 50 per cent). Bulldozers can compact the soil to a depth of 3 ft (Matena, 1958), but time and good management improve the soil structure. Loess banks 18 years old showed a pore volume of 44 per cent, but we do not know whether they had any earlier compaction.

The second danger is *siltation*. The raw loess has no stable crumbs, but is highly susceptible to siltation by rain and bad drainage. Siltation itself means lack of air for the plants and so decreases the yield. A permanent plant cover and higher humus content are the best means of dealing with this problem. The sooner plant growth starts after mining, the better.

The third danger is *erosion*. Running water can cause erosion of the raw loess on very soft slopes of more than 3 per cent. Enrichment by the addition of

EXPLANATION OF FIGURE

FIGURE 8. Mining equipment in German opencast mines.

A Bucket ladder (or chain) excavator.

$\frac{1400}{38-40}$. The buckets are mounted on two movable chains and held by a

ladder. Length of the ladder, 200 ft; cutting depth, about 107 ft; average daily capacity, 58,000 cubic yards of virgin overburden; built in 1936. At rear, a small bucket ladder for grading a working bench. Spoil hauling by trains. Lausitz, 1953.

B Bucket-wheel excavators and conveyor belts

These are characteristic of modern German lignite opencast mines. Rhineland, 1959.

C Bucket wheel in operation

Diameter of wheel 53 ft. Daily capacity 130,000 cubic yards of virgin overburden. The wheel can separate overburden and coal of different qualities. Rhineland, 1959.

D Covering of ungraded spoil banks

Ungraded toxic spoil banks (left) have been covered by nontoxic material by trains (right). On the top of this, a second cover of fertile topsoil is spread out (in the background right). Direct covering of ungraded banks would waste the small quantities of topsoil available. Mining district of Halle, 1954.

E Spoil-spreading plant

Daily capacity more than 200,000 cubic yards of virgin overburden. Spoil haulage by belt-conveyor system. Rhineland, 1959.

F Loess transportation in pipe lines

Loess can be pumped in pipe lines if mixed with water 1:2. The basins can be easily prepared by bulldozers. If the subsoil is permeable the mud dries out within a few weeks and can be seeded with alfalfa or other plants. Costs are relatively low. Photo Deutsche Bauernsiedlung, Rhineland, 1960.

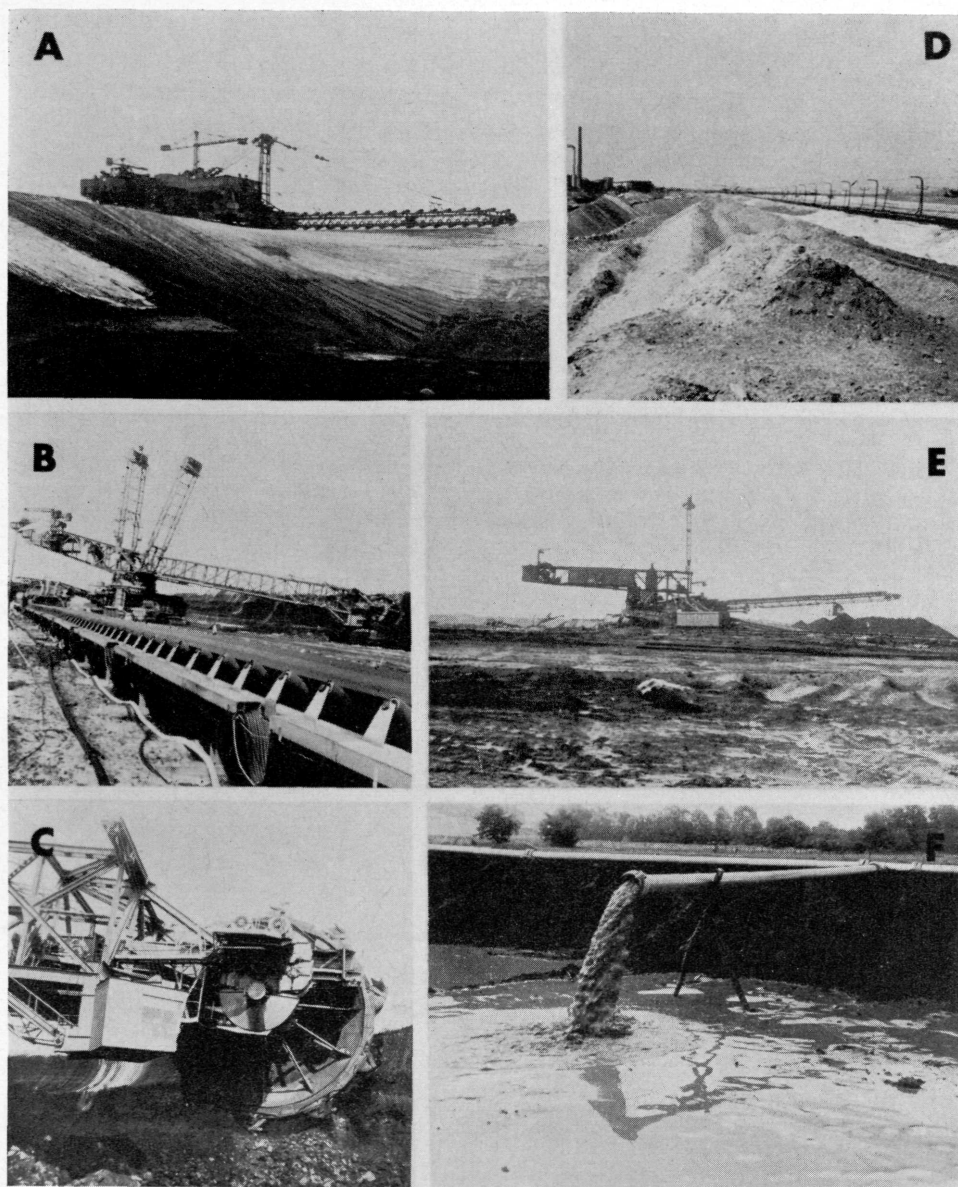


FIGURE 8

humus and building up stable crumbs is the best way to prevent erosion, but a nearly flat field is also required.

Werner (1961) recommended two different rotations for enrichment by humus (table 3).

TABLE 3
Proposed rotations for loamy spoil banks near Leipzig

| Year | Proposal 1 | Proposal 2 |
|------|--|--|
| 1 | Rye with alfalfa | Mixture of barley and oats with white clover and alsike clover |
| 2 | Alfalfa | Clover mixture |
| 3 | Alfalfa with orchard grass | Rye with alfalfa |
| 4 | Alfalfa with orchard grass | Alfalfa |
| 5 | Potatoes (with manure) | Alfalfa |
| 6 | Rye with a mixture of white clover, alsike clover, grass | Alfalfa |
| 7 | Clover-grass | Corn |
| 8 | Corn | Rye |

The mixture with the white clover, which does not bring as high yields as alfalfa, helps to cover acid spots where alfalfa will not grow. The orchard grass will grow better if seeded in the spring of the second or third year of the alfalfa stand, after heavy harrowing. In the loess area of the Rhineland, alfalfa is also the most frequently used plant for site amelioration; wheat and sugar beets follow. But Schulze and Engels now recommend an annual type of sweet clover (Hubam clover) as the better plant, because:

- (1) It can be sowed at any time during the growing period, whereas in the Rhineland, sowing alfalfa is restricted to the early spring.
- (2) It is more tolerant to soil compaction and unsatisfactory water conditions; it grows more quickly, covers the ground more rapidly, and produces a higher yield of green manure.
- (3) It is more effective in stimulating soil life, and on the whole brings the crude soil into a healthier condition.

EXPLANATION OF FIGURE

FIGURE 9. Views of strip-mined areas

- G "Lunar landscape" in area mined by belt-conveyor bridge. The mixture of all strata is extremely toxic and highly erodible. Last cut partially filled by eroded material. By 1963, about 500 acres of this area have been ameliorated by using brown-coal ash and fertilizers. Lausitz, 1957.
- H Wheat on reclaimed spoil banks. Helmstedt, 1961.
- I Recreation area in the Rhineland
Beautiful lakes and forests are the results of strip-mining and good reclamation. Rhineland, 1955.
- J The second generation of a mixed hardwood forest planted after heavy thinning of the *Vorwald* of hybrid poplar. Beeches and maples are growing well. This was done to improve the scenery of this recreation area. Timber production needs more time. Rhineland, 1961.
- K Planting follows spoil disposal. Poplar plantations in the first, second, and third year after planting. The sooner tree planting after dumping of the spoil the better, if the material is not toxic. Rhineland, 1955.
- L Successful amelioration of toxic spoil bank in the Lausitz mining district. Area mined in 1917, planted twice without success. Amelioration of small strip in 1955-56 by application of ash of brown coal and NPK. Poplars and alders in second year of growth. Lausitz, 1957.

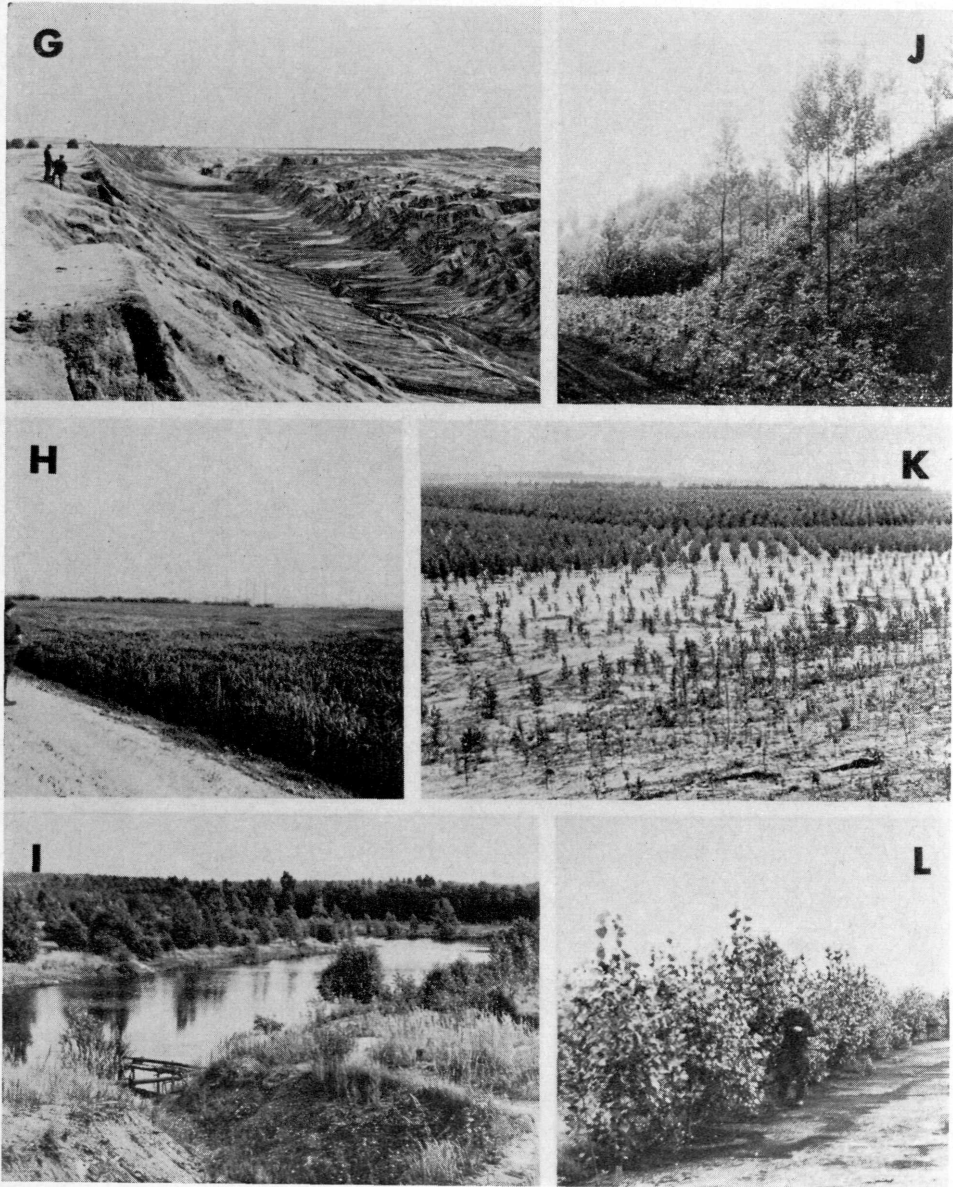


FIGURE 9

Hubam clover has to be mowed after flowering and before ripening of the seed in order to prevent competition with the next crop. Since it contains coumarin, this clover is not proper feed for cattle. Hence, small farms that need the fodder will use alfalfa.

Fertilizing is another important factor in agricultural reclamation. Soil samples show lack of nitrogen and phosphorus, and sometimes potassium. But the legumes seem to be able to use more phosphorus than is detected by the usual lactate method. In the Rhineland, best results were found by the application of both manure and green manure in addition to fertilizers.

Schulze and Engels (1962) recommend about 140 kg pure nitrogen and phosphoric acid/ha (0.062 ton N or P_2O_5 /acre) and 200 kg pure potash/ha (0.088 ton K_2O /acre) for grains. For yields of greatest quantity and best quality, sugar beets need more than double these amounts. Green manure can reduce the application of nitrogen fertilizers. All authors since Mampel (1929) and Hundhausen (1935) state that crude loess soils should not be farmed without cattle, because the manure is urgently needed to enrich the humus and stimulate soil life. Werner (1961) found that only deep plowing will distribute the given nutrients in deeper layers, where they are needed to increase the living space of the plants. Plants with narrow root systems will suffer most in dry periods.

So far, there is no definite answer as to how much topsoil or cultivated soil should be spread over the bank. On toxic spoil material near Leipzig, Seidemann (1961) found a definitely increased yield when the sandy-loam topsoil was increased from 1 ft to 40 inches. But Naujocks (1962) found no difference during the first year between loess covers of 2 and 7 ft. Oestrich (1961) reported that more than 40 inches of loess caused decreasing yields on fresh spoil banks, probably because of poor drainage. Further investigations are needed to answer this question. Schulze and Engels (1962) have announced the forthcoming publication of their results in an early number of the *Zeitschrift für Acker- und Pflanzenbau*.

In this connection I want to repeat one sentence. "The success of reclamation must be judged by the yield in this last period of permanent use and not by the output of the pioneer crops." Scientific studies of the many questions involved are necessary. The results of the first years of cultivation of the spoil are interesting and of great value, but we shall not have a definite answer until the crude loess has a humus content and a maturity comparable to those of an undisturbed loess soil of the vicinity.

AFFORESTATION OF SPOIL BANKS

It is now time to discuss some German experiences with forests in strip-mine reclamation. You will be interested to learn that as early as 1784, the Duke of Cologne, Max Friedrich, ordered the open pits of little surface mines planted with alder. But current experiences are available only from plantations after 1906 in the Lausitz mining area, and after 1920 in the Rhineland. Most of the German foresters now accept the following principles of strip-mine reclamation:

1. The afforestation of a spoil bank is not a single act, but the beginning of a long process of forming new forest lands adapted for multiple use by many coming generations.
2. Hence, the first stand is only a nurse crop, with the function of
 - (a) covering the barren area
 - (b) protecting it against erosion
 - (c) changing the raw spoil into a living soil.
3. The forester has to look for trees that are able to withstand the special conditions of spoil banks: no shade, no organic matter and soil life, and insufficient nitrogen; also lack of competition with other plants in the early years, and in many cases a loose structure which allows a quick and deep root growth.

4. Since we are concerned with our own welfare as well as that of coming generations, it is the forester's duty to select those pioneer species that yield commercial products—pulpwood, timber, or Christmas trees. There are only a few sites for which you can find no species of commercial value.
5. Next to pulpwood and timber production, provision for outdoor recreation will be the most important function of these new forests. In many cases it will be more important than any other (fig. 9I, 9J).

I will now try to describe normal afforestation of spoil banks in Germany. In the Rhineland, the afforestation is preplanned by the forest department of the mining company. The mining department announces the areas to be planted next, and then the foresters check the site conditions. These are generally the same as in previous plantings, namely, sandy gravel mixed with loess. After that they decide which tree species should be planted. The usual combination is hybrid poplar (*Populus euramericana*) with European black alder (*Alnus glutinosa*). For many years a 10 x 10 ft spacing for the poplars and a 5 x 5 ft interplanting with alder were used. Due to the present-day costs of trees and labor, this plan has been changed. Hybrid poplars now cost about \$42 a hundred, and the planting, \$25 to \$40; 100 alders can be purchased for \$4 and planted for much less than the poplars. Hence the poplars are now spaced at 13 to 18 ft. Poplars need deeper planting, 12 to 16 inches deeper than in the nursery. The planting is usually done by nursery and planting operators, rather than personnel of the mining company. Poplars and alders are growing pretty well and reach pulpwood size in 8 to 12 years; the first poplar timber can be harvested in 18 to 20 years (Gaertner, 1962). In about 35 years, logs for plywood can be cut, even earlier on the best sites and in free stands. The alders help to prune the poplars, which must have still enough crown volume if they are to bring economic yields. Thinning is therefore a necessary part of the management of poplar stands.

If a German forester uses the name "poplar," he is thinking only of the hybrids of the section *Aigairos*; this denotes crossings between European and American species, for instance *Populus nigra* x *P. angulata* or x *P. deltoides*. And so am I. But I ought to mention that there is now an increasing interest also in balsam poplars (section *Tacamahaca*) and the different crossings between *P. alba*, *P. tremula*, and *P. tremuloides*, as well as in new clones of tree willows.

The poplar-alder plantations improve soil conditions. Their roots grow very deep in the loose ground, not on compacted areas, and in a short time litter and humus produce a kind of forest soil. Very important is the ability of all alders to fix nitrogen from the air by a ray fungus, *Actinomyces alni*. Although they are not legumes, but belong to the birch family, they are similar in this respect to the black locust. Nonwoody legumes like the blue perennial lupine (*Lupinus perennis*) also may be used successfully instead of the alder.

Wemper (1962) warns against the use of sweet clover because of its competition with young plants, but if it is used some years after planting this danger will disappear. In the 1920's and 30's, foresters tried many other species: pines, beech, oaks, hornbeam, birch, larches, and Douglas fir, but no other species produced the same yield as the poplar.

The large poplar-alder plantations fulfilled their functions of economic return and soil improvement, but the public did not like their predominance in the whole mining district. During winter one could see the endless areas with rows of bare trees, and even in summer they sometimes looked too monotonous (fig. 9K). But no other tree would have formed a green forest so quickly, not even the black locust (*Robinia pseudoacacia*), which was often used in the early years of reclamation.

The public interest was one reason that Hochhaeuser (1961) recommended other pioneer trees. Austrian pine (*Pinus nigra*, var. *austriaca*), European larch (*Larix decidua*), Douglas fir (*Pseudotsuga taxifolia*), red oak (*Quercus rubra*) and

black locust have done well in the first generation. Scotch pine (*Pinus silvestris*) and Japanese larch (*Larix leptolepis*) showed stagnation or died back after about 20 years. The pine does not seem to tolerate the pH of 6.5 to 7.0; the Japanese larch is not resistant to low rainfall and dry periods.

Fortunately, many of the older stands in the area are now to be underplanted with other trees. European beech (*Fagus sylvatica*) and Douglas fir (*Pseudotsuga*) are two of them, but we still have to learn what trees are the best for the second generation. In fig. 9J, the economic maturity of the poplars has not yet been reached; the aesthetic purpose was the important one for the heavy thinning. European beech can be planted as first generation also on the best sites with high loess content.

The Lausitz mining district is the other great area for strip-mine afforestation. It has the oldest plantations that I have seen in Germany. The most beautiful was a stand of red oak (*Quercus rubra*) planted in 1907 by a horticulturist, Mr. Muschner. In the following years the mining companies planted many tree species, but the site conditions were not so good as in the Rhineland. Hence the investigation of spoil conditions before planting was essential for success.

But I must mention two other names, Heuson and Copien, who were the outstanding strip-mine foresters before World War II. Heuson (1947) had recommended the broad use of European black alder since 1929. This species is very helpful, not only as nurse tree but also because it produces no root suckers, which are typical for its sister, the European speckled alder (*Alnus incana* Moench). Thus silvicultural management was much easier than before.

Heuson also recommended planting immediately after dumping in order to use the loose structure which most pioneer trees like. He was in a hard literary struggle with Copien (1942) about planting or not planting pines on fresh spoil. Since the Scotch pine is the commercial tree of this sandy area, Copien recommended wide use of pines. Heuson opposed this because he wanted first to improve the soil. Twenty years later, foresters in the Lausitz still use pines, but mixed with alder, herby legumes, or other hardwoods, and not to the same extent as formerly. The result of the struggle was a balance between economic and biological considerations. In spite of those first experiences, recommendations for forest reclamation were based more on silvicultural opinions than on scientifically proved facts. I mean that there were available no exact comparisons between different tree species or mixtures on different spoil types and no pedologic inventory of the spoil banks. We did not know very much about the relations between site conditions and the growth of trees or the influence of hardwoods or softwoods on soil development on raw spoil.

To get better information about the choice of tree species on the different spoil types, I started experimental plantations with 28 tree species and six hybrid poplars in 1954. We repeated the experiment in 1955 and 1956 in order to secure results independent of weather and other factors.

Later on, we included many additional trees and shrubs in our program. After five years we could compare the increment of the first three series over a period of three years. We found great differences in survival and growth between the species and on the different spoil mixtures. But some trees also showed very different results in the different years of planting.

Some of the results after three years may be summarized as follows. The figures in parentheses are increment of height (cm) or survival (%).

- (1) On fresh calcareous spoil banks of clayey and sandy glacial till, only the nitrogen-fixing European speckled alder (218 cm), European black alder (161 cm), black locust (162 cm), and the shrub *Hippophaë rhamnoides* (91 cm) were able to use fully the other nutrient elements during the first 3 years. All these species had a survival of more than 80 per cent. Next in turn were aspen (84 cm), and hybrid poplar (68 cm). All other species had a slow start; none exceeded 30 cm increment.

- (2) On poor sands of glacial outwash, the speckled alder (86 cm), black alder (53 cm), black locust (72 cm), hybrid poplars (about 55 cm), and aspen (47 cm) showed about the same survival, but did not reach the same height as on the glacial till.
- (3) On marginal sands, a mixture of glacial outwash and very acid tertiary micaceous sand, about 50 per cent of the black locust and hybrid poplar died. They cannot be recommended for these sites. Speckled alder (28 cm), black alder (19 cm), and aspen (58 cm) still had a survival of 80 per cent, but except for the aspen, their increment was very low.
- (4) One group of trees on all three sites showed a low, but fairly uniform, growth in height. These are Scotch pine (26, 25, 25 cm), white pine (12, 13, 13 cm), European white birch (24, 25, 26 cm), and red oak (6, 8, 5 cm). They showed greater differences in survival.
- (5) There were many other species with a survival of 90 per cent or more on nontoxic spoil banks, but they showed hardly any growth in height. This group includes Norway maple, flowering ash, European ash, hornbeam, Mahaleb cherry, wild black cherry, mountain ash, linden, common horse chestnut, hawthorn, European bird cherry, and elm.
- (6) Other trees, such as Norway spruce, Douglas fir, and European beech showed neither good survival nor remarkable growth in height.
- (7) The greatest differences of survival with respect to the planting years were shown by hedge maple, sycamore maple, European white birch, Scotch pine, Austrian pine, Douglas fir, and European larch. Variation in planting time and quality of planting stock may account for the differences.

Further observation of these experiments is necessary to check the results. There are only a few records of height and volume growth of older plantations.

Table 4 gives some results in the Lausitz, in comparison with others from the Helmstedt area near Braunschweig.

TABLE 4
Growth of different stands on spoil banks in the Lausitz and Helmstedt mining districts

| | Age in years | Height m | Diameter bh. cm | Number of trees/ha | Volume cbm/ha |
|-------------------------|-----------------|-------------|--------------------|-----------------------|------------------|
| 1. <i>Lausitz</i> | | | | | |
| a) European white birch | 26 | 12.4 | 13.6 | 992 | 84 |
| b) Mixture of | | | | | |
| hybrid poplar | 29 | 23.0 | 36.8 | 76 | 72 |
| black locust | 29 | 18.6 | 19.4 | 496 | 133 |
| sycamore maple | 29 | 8.2 | 7.8 | 132 | 2 |
| | | | | Su. 704 | 207 |
| c) Scotch pine | 37 | 10.6 | 11.6 | 3128 | 142 |
| d) red oak | 49 | 17.7 | 18.2 | 756 | 164 |
| 2. <i>Helmstedt*</i> | | | | | |
| Mixture of | | | | | |
| hybrid poplar | 29 | 22.5 | 38.0 | | |
| black locust | 29 | 20.4 | 26.4 | | |
| European ash | 29 | 16.5 | 19.0 | | |
| European white birch | 29 | 15.4 | 18.8 | | |
| Norway maple | 29 | 15.0 | 15.8 | | |
| sycamore maple | 29 | 14.6 | 15.0 | | |
| linden | 29 | 12.8 | 16.6 | | |
| durmast oak | 29 | 11.7 | 11.3 | | |
| red oak | 29 | 11.6 | 12.4 | | |
| European beech | 29 | 11.5 | 15.0 | | |

*Hohmuth 1962.

Even these few results show that hybrid poplar and black locust are the fastest growing trees still at the age of 30 years. Black or speckled alder have improved the growth of stands 1c, 1d, and 2, but they have now been cut out and their effects cannot be determined precisely.

The study of older stands and young experimental plantations enabled us to present a preliminary planting guide for the Lausitz mining district (Knabe, 1959c).

I want to bring the proposals for two of seven spoil types to show the kind of mixtures we like, I must remind you that the spoil in this area consists mostly of sand.

1. Recommendations for best sites—sand with high content of loam or glacial till and topsoil.
 - (a) Hybrid poplars with black locust and linden (*Tilia cordata*)
Hybrid poplars with European black alder and European speckled alder
 - (b) European larch (not under pH 5) with linden, European black, and speckled alder
 - (c) Scotch pine or Eastern white pine (*Pinus strobus*) or Austrian pine with European black alder or perennial lupine. Black locust can be underplanted in older pine stands
 - (d) Durmast oak (*Quercus petraea*) with sweet cherry (*Prunus avium*), Sycamore maple (*Acer pseudo-platanus*), Norway maple (*Acer platanoides*), and linden with 25 per cent of alders
 - (e) With less loam and pH between 4.0 and 6.0, it is better to use northern red oak with linden, wild black cherry (*Prunus serotina*), and European black alder.

I will omit spoil types 2 to 4 and 6 to 7.

5. Recommendations for strongly acid, poor sands without topsoil (pH 3.5 to 4.5).
Without amelioration only the following mixtures should be used.

- (a) Aspen (*Populus tremula*) with English oak (*Quercus robur*), European black alder, and wild black cherry.
- (b) Northern red oak with European black alder and wild black cherry.
- (c) European white birch (*Betula pendula* = *B. verrucosa*) with black alder, English oak (*Quercus robur*), black wild cherry, and eventually mountain ash (*Sorbus aucuparia*).

After liming up to pH 4.5 to 5.5, fertilizing, and seeding with perennial lupines or St. John's rye (*Waldstaudenroggen*) much higher yields of the trees mentioned above will be obtained. Then Scotch pine also can be planted with good results. Guenther (1958) used summer refuse for amelioration of such sites and was able then to plant poplar cuttings.

You will be interested to learn that spacing of pines is much closer in Germany than here: 1 or 1½ x 4½ ft, or, sometimes on spoil banks, 2½ x 2½ ft. The purpose of the close stand is to provide an early cover and self-pruning. I do not know whether this is better than wide spacing and artificial pruning, but I have to mention it. Alders were interplanted between the rows, but they need early thinning or pruning to prevent top shading.

AMELIORATION OF SPOIL BANKS

Amelioration means a single treatment of a site to make possible or to increase the growth or yield of plants for a longer period. Subsequent good management can maintain this new level of productivity.

Any amelioration should consist of four phases:

- (1) Investigation of the limiting factors which prevent good plant growth
- (2) Development of methods to overcome these difficulties and testing these methods in order to discover the cheapest way to carry them out
- (3) Application of the best method on the area
- (4) Control of the result.

The first phase is a matter of applied natural science. Site and soil investigations, field trials, and greenhouse studies are the appropriate means. Scientific, technical, and economic considerations are involved in the second phase. The application needs only good organization of the available equipment and adaption to variations of site conditions. The control will show whether the amelioration was successful from the biological and economic points of view. It should not be omitted as is often done, because we need this information for later application.

On spoil banks we find some limiting factors, such as lack of nitrogen, which can easily be removed by biological methods alone. The planting of alder, black locust, or perennial lupine in forest reclamation, and the use of alfalfa or sweet clover in agricultural restoration have been mentioned. The latter, however, are not sufficient to meet the high nitrogen requirements of some crops.

Other locations need a combination of chemical, mechanical, and biological methods. The cultivation of toxic *Kohlenletten*, a soft sandy shale with a high content of amorphous coal material and pyrite, is the best example.

Soil investigations of this material detected high acidity (pH 2.0 to 3.5) and high content of soluble manganese and aluminum, but lack of phosphoric acid, potassium, and magnesium. Observations on the banks showed a strong water repellence, which prevented the infiltration during summer rains. Kraemer (1935) explained this as a result of fossil wax, and Kopp (1960) by hydrophobic compounds of humus and iron. I found that the water repellence disappeared after an extraction by alcohol and came back if one dropped the extract back on the surface. From 1952 until 1954, greenhouse studies proved that plants could grow on the same toxic material if enough lime and fertilizer were added (Knabe, 1959a). That was the first phase of investigation of the limiting factors.

In the second phase since 1955, different methods of amelioration were tested in field trials on the toxic spoil banks themselves. Best results were obtained by use of the refuse of the power plants near by, the ash of brown coal. This calcareous and hygroscopic material neutralized the acidity and removed the water repellence. It also contained some nutrients, especially calcium, magnesium, and potassium. Nitrogen and phosphoric acid had to be added afterwards.

On areas where the distance to the nearest source of ash was too great, application of lime (8 ton/acre) and fertilizers was more economic. This method was used by Bruening (1959) on toxic banks in Boehlen.

But only mixing of ash or lime and toxic spoil material could bring good results. Natural infiltration of calcium is very low if the water does not have high content of CO₂. Summer refuse with a high content of organic material may be used without tillage. But heavy disking with rotary hoes for mixing with the upper soil, followed by deep loosening and mixing with the subsoil by plows was proved to be the better way to use lime and ash. One has only to avoid covering the ameliorated layer by fresh toxic spoil from the subsoil. My former colleague Schaelicke has developed a special type of plough for that purpose.

This chemical and mechanical combination has to be completed by biological methods. Grass, especially red fescue, was found to be the best plant for production of organic matter. The grass can be plowed in some years later as a green manure for trees. Planting of trees is also possible without the use of grass if it is done some months after the application of ash or lime. Weathering of fresh pyrite, the reaction between acids and bases, as well as the transformation of free calcium into carbonaceous calcium or soluble boron of the ash into non-soluble compounds need some time.

The broad application of these methods has been made on the toxic spoil banks of Domsdorf since 1957. Figure 9G shows the very bad situation before this was done. Great parts of this area are now green. But I cannot return to my old experiments, because the border cuts off Mideastern Germany for all who ever left it.

And now for the control. The biological result was much better than expected. Hybrid poplar, red alder, aspen, white birch, and red oak grew very well on these ameliorated sites, much better than on the sandy spoil banks which had never been toxic. The hybrid poplars, e.g., in the second year after planting, produced shoots averaging more than 4 ft (fig. 9L).

But let us consider the economic results. Spreading two inches of ash was much cheaper than covering the spoil with 4 ft of cultivated soil from another mine. The mining industry would like to abandon the old practice of separating fertile spoil in favor of later amelioration for forestry. But our present knowledge does not allow this easy solution; we have to look also for the production of large quantities of salts and acids in the mixed banks, which affect the water resources. And we know that the mixed spoil has much greater variation than a single layer. This mixed material will hardly be as good for cropland as loess or a loamy topsoil, whereas it is usable for forestry and eventually for pasture. We recommend the application of ash at least for all old toxic spoil banks, where no topsoil or other layer can be used for covering.

This positive economic judgment will not be altered by the fact that the income from the first generation of trees cannot exceed the costs of amelioration; this is true for any kind of reclamation. It may be true, as some hope, that time alone will heal the worst scars of mining (fig. 9G), but we cannot wait a hundred years or more, and after 40 years we did not find any green on this type of bank. Such a densely populated and highly industrialized country as Germany has to find better solutions and remedies that work faster. We do not want to be blamed as a wasteful generation by our children and grandchildren. We have the technical equipment, the knowledge, and the money to recreate a pleasing and fertile land. We would be foolish if we were to ruin our country instead of using all our resources for the restoration of the land itself, which still is the basis for any nation.

SUMMARY

I want to summarize my report. Germany is the country with the highest production of brown coal in the world: 225 million tons are produced in Mid-eastern Germany, 94 million tons in Western Germany—a total of 319 million tons, more than 95 per cent in open-cast mines. The seams of lignite are many times thicker than the seams of bituminous coal in Germany or the United States. Lignite opencast mines can remove, therefore, much higher layers of overburden. In Western Germany these now have reached a depth of 400 ft, and mines with 1,166 ft of overburden and 233 ft of lignite at the deepest point have been planned (Gaertner, 1962).

Spoil disposal in Germany is not a single act as in most American strip mines, but a combination of digging by bucket-wheel or bucket-ladder excavators; transportation by trains, shiftable conveyor belts, or a conveyor-belt bridge; and dumping by spreading plants or the conveyor-belt bridge itself. This technical development is a German one, whereas auxiliary equipment has been strongly influenced by American earth-moving equipment.

Reclamation is regarded as an integral part of mining (fig. 2); hence laws in Western and Mideastern Germany require the pre-planning of reclamation. Olschowy (1961) and Darmer (1961) explain in detail the principle of reclamation of a whole area instead of restoration of a single field or forest, which was formulated still earlier.

The most important component of reclamation in German opencast mines is the separate disposal of topsoil or fertile layers like loess, in order to cover the spoil banks after grading and to provide a basis for good crops. The investigation of the agricultural value of the different layers before mining is therefore very important. Agronomy and forestry have developed methods of reclamation of all spoil mixtures, even the toxic ones. Alfalfa and sweet clover have been found

the best soil-improving pioneer plants for field crops, and alders, black locust, and perennial lupines for the afforestation. Hybrid poplars brought the highest yields on some, but not all sites. Toxic spoil banks need a special amelioration. The use of ash of brown coal in combination with NPK fertilizers and heavy disking has proved to be the best method. Further scientific work is necessary and is carried out at different research stations in Western and Mideastern Germany.

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DISCUSSION

GERALD R. TENNYSON, *Milwaukee*: I would like to direct the following question to Dr. Knabe:

What other equipment is used for mining and reclamation besides the wheel excavator?

DR. KNABE: Bucket wheel excavators are the main type of equipment built for excavation in German lignite mines during recent years. Besides those, many older bucket chain excavators are still used. We do not work with the big power shovels and draglines you have in the United States, except with small types as auxiliary equipment.

But excavation is only one part of a German surface mine. Hauling, spreading, and grading are the other phases of spoil disposal. I did not mention the grading equipment. We usually use bulldozers, crawler-mounted or with rubber tires. But I remember an old experiment with a set of two old steam tractors which drew a grading plane back and forth. The plane consisted of two parallel-mounted iron rails with a length of 33 ft. The rails were connected at a distance of 7 ft by two thin iron rolls at the front and back. The grading effect is the result of two blades mounted between, which move the spoil from the ridges filling the valleys.

You can find general information about the equipment in *Gaertner* (1954, 1955), Gold (1952), Kegel (1953), Kirst (1951, 1952) or in the recent issues of the German mining journals *Braunkohle*, *Waerme*, *Energie*, Duesseldorf, and *Bergbautechnik*, Berlin (East).

R. FRANK, *Kingston, Pennsylvania*: I would like to direct the following question to Dr. Knabe:

After a nurse crop has been established, what method or procedure should be followed in order to convert the stand into one which consists of more valuable species?

DR. KNABE: This question requires an economic, biological, and silvicultural answer. Nurse crops on strip mines in Germany mainly consist of merchantable tree species. We do not have comparisons between the yield of this pioneer stand and the second generation. Therefore we are not able to say that the second wave will generally consist of more valuable species than the first one.

The main pioneer trees used for reclamation are poplar, alder, and pine. The young poplars have been sold as pulpwood and as raw material for container boards or chip boards. Since poplar is light in weight and light in color, the container industry prefers this species. Container boards from heavy wood like oak are not so easy to handle and do not have such a nice appearance. Bigger sizes of poplars are used mostly as saw timber for boxes, but also by the match industry for producing matches and as veneer in plywood. If anyone wants more information concerning the use of poplar he can write to the German Poplar Association (Deutscher Pappelverein und Lignikultur in Bonn, Kronprinzenstrasse 16).

Young alders can be used for chip boards too, medium sizes having been sold as pit-wood. We don't know if the alder will reach bigger sizes on spoil banks. It can be used for under water structure, cigar-boxes, plywood, etc. Pines which are often planted as first generation in the Lausitz are used for the same purpose there as in America.

But it is clear that the financial yield of the first generation of trees will usually not exceed the costs of the whole reclamation. That needs more time. Now we come to the biological answer.

I used the term nurse crop as an unsufficient translation of the German term *Vorwald*. I am better using the German terms.

Weck (1948: 8) has described four stages of a natural succession on a non-forested area under conditions which allow a forest cover:

First stage: Vorwald (nurse crop, nurse stand, pioneer stand)

Second stage: Zwischenwald

Third stage: Hauptwald

Last stage: Schlusswald (climax)

The *Vorwald* is called the first type of forest cover which develops on a bare area. Its trees can grow under full light, but often have to suffer under frost and heat, continuing and strongly blowing winds, and fluctuations between abundance and lack of water (Weck, 1952).

If the bare land is a clear-cut area, they can use the old forest humus; on spoil banks or old fields they have to develop a forest soil. These pioneer trees generally have a fast youth growth, but an earlier slowing down of increment than trees grown under shade. The timber of douglas fir from German plantations, for instance, has wide annual rings in youth and very narrow ones later on. Therefore it has much less value than the douglas fir timber with rather uniform annual rings grown in the virgin forests of Washington under the shade of a pioneer stand of red alder.

The second stage, or the *Zwischenwald*, develops under the shade of the pioneer stand, if no further interruption occurs. The new growth may be the same species as the pioneer trees, but usually other species invade naturally. They have another development as under the full light of the *Vorwald* stage. The *Zwischenwald* leads to the third stage, or *Hauptwald*. That is a forest type with many shade-bearing trees, but where regeneration still takes place, and we find trees of different age and height. This type usually has the highest increment.

The end of the natural succession is the *Schlusswald*, or climax, in which we hardly find any natural regeneration and little increment, until a breakdown of overmature trees or a fire allows a new cycle to begin.

Now let us come to the silvicultural consequences. The forester can make use of these natural successions. He can plant the second wave under the protection of the pioneer stand on many sites and come, in the third generation, to the highest productive type of the *Hauptwald*.

By this method he uses the natural process of maturing of the new forest site. Sometimes trees of the second wave can be planted at the same time as the pioneer trees, but usually it is better to wait until they have some protection.

Later underplanting of trees after development of a dense canopy of the pioneer stand requires a thinning management, but often the early losses among the pioneers can be used, thus saving labor and money.

I want to go back to the original question. It is possible to underplant poplar-alder plantations on spoil banks with about all tree species adapted for the special spoil material if they can bear at least some shade. European beech, maple, linden, and hornbeam have been tried; douglas fir, western hemlock, and other species still have to prove their usability. The other silvicultural way to reach a second generation would consist of clear-cutting followed by reforestation. This often seems to be the easier way, but we give up an important part of the natural maturity of the new forest site. It is a new beginning, better than the first one on the bare area, but worse than a link of natural succession.

W. G. JONES, *Philipsburg, Penn.*: I would like to direct the following question to Dr. Knabe:

How soon can a crop of pulp wood be expected from a hybrid poplar planting and what is the minimum diameter of your pulp wood in Germany?

DR. KNABE: The first crop of pulp wood can be expected from a hybrid poplar planted on spoil banks of the Rhineland after 8 to 12 years (Gaertner, 1962).

The minimum diameter of our pulp wood is about 7 cm or $2\frac{3}{4}$ inches. The movable machinery which chops the pulpwood into pieces in the forest can also use smaller diameters down to 2 inches or less, but we have not used these machines on strip mines and therefore have no experience concerning costs and results.

H. A. WILSON, *Morgantown, West Virginia*: I would like to direct the following question to Dr. Knabe:

Have any studies been made on the increase of water-stable aggregates under the various plants on reclaimed spoil?

DR. KNABE: I do not know any special studies concerning water-stable aggregates under various plants on reclaimed spoils.

But investigations have been carried out concerning the results of different plants on the number of bacteria, fungi, and actinomycetes in reclaimed spoil material, which may be interesting for you (Bruening, 1961; Feldmann in Schulze and Engels, 1962).

I think the Library of Agriculture, Washington D. C. has these publications available.

EDWARD A. LESENE, *Knoxville, Tennessee*: I would like to direct the following question to Dr. Knabe:

Is any contour stripping done in steep topography in Germany, and if so, how is the overburden handled?

DR. KNABE: We do not have contour stripping in steep topography in German coal mines. Surface mining is restricted to the brown coal areas, where we have level or hilly topography only. The layers of bituminous coal that were mined in the last century were near the surface; in 1957, the average depth of the mined bituminous coal seams lay at about 760 m or about 2500 ft.

MR. LEUTY: In regard to ground water level, what is the range of the cone of influence on surrounding wells when ground water is pumped for coal excavation?

DR. KNABE: Brown-coal surface mining cannot be done without lowering the ground-water table (fig. 2). The water level in the surrounding of a single mine will have the shape of a cone with its deepest point in the open pit. The diameter of the cone depends on the depth of the open pit and the geologic conditions.

I cite some figures that I got from Dr. Lehmann and Dr. Bollmann (Knabe, 1959a). Impermeable layers can stop the lowering 1,000 ft from the highwall; permeable sands in the Lausitz can be affected even at a distance of 6 to 8 km, or 11 miles from the nearest open pit. By overlapping of the cones of different mines, a great area can be affected. Bollmann estimated that about 628 square miles were affected in Mideastern Germany.

In Western Germany the lowering of the ground-water level of great parts of the Erft valley is necessary. Heide (1960) cited some calculations of Kiel (1956). The cone of lowered ground water will amount to 425 square miles, perhaps up to 1,000 square miles.

Scientific investigations have begun to determine the results of the changing water conditions for croplands, pastures, and forests (Kolloquium . . . , 1962). But that is another question.

R. H. COLEMAN: I would like to direct the following questions to Dr. Knabe:

How many acres are affected by surface mining per year, and can a property owner control the degree or amount of restoration?

DR. KNABE: Brown coal surface mining covers between 1000 and 1200 acres per year in Western Germany, about 5000 acres in Mideastern Germany. The total area affected by 1962 can be estimated to amount to 43,000 acres in Western Germany and 170,000 acres in Mideastern Germany. Beside that, an area of about 2,500 acres per year is supposed to be affected by surface mining for gravel and sand in Western Germany alone.

The control of reclamation by the property owner has changed. Before the last war, agricultural reclamation was mostly based on private contracts between land owner and mining company. Now in Western Germany the law requires so much work for the mining companies that the land owner does not have reason to ask for much more. There are two possible methods by which the land owner

may have an influence: First, he may work through his community and farmer associations, which are both members of the planning courts; secondly, he may work through his private contract with the company. The farmer associations and communities can influence the relation between agricultural and forest reclamation. They can make proposals at the time of preplanning. Before resettlement of a village, the inhabitants can decide by voting if they want a new single village or if they prefer to become a suburb of the next city. After the general decision has been reached, the company has to make private contracts with the single property owners.

If a mine covers a large area in its time of life, there are many land owners and the planning court has to find a way to satisfy all, and therefore the freedom of the single inhabitant is limited. If the landowner sells his property to the company, then he has no further influence. If he wants to get farmland back, he cannot wait for his old property. He would have to wait sometimes 15 to 20 years till mining is finished in these very deep opencast mines. After that, a period of 3 or 4 years follows with soil-improving management by the Company. Therefore, the farmer will get other farm land on undisturbed land or on land affected many years before.

He is free to make his proposals, and if it is possible to follow these proposals they will do so. The company is generally very generous and tries to see that everybody is satisfied. I only know of two cases where the owners went to court to fight against the company. On the other hand, there have been thousands of cases where an agreement was reached between farmers or homeowners and coal company, and both sides were satisfied.

In Mideastern Germany we have a different situation, because the private farmers were forced to join so-called cooperative farms and the mining companies were socialized after World War II. Therefore, the individual farmer has hardly any control over reclamation. The cooperative farm can ask for restoration of its land and reclamation is more or less a case between the different administrations. In some counties and districts, the agricultural administration has good cooperation with the mining administration; in others it has very little influence. They have the legal basis for good reclamation, but in many cases that is not sufficient.

MR. A. KAUFMAN, E. H. MONTGOMERY, *Washington*, and MR. R. M. REESER, *Columbus*: raised some questions concerning the costs of reclamation in Germany:

DR. KNABE: The question of costs of reclamation is a difficult one. Reclamation is an integrated part of strip mining in Germany. It is not easy to fix or separate the costs of this special procedure, even if the companies would like to give you their figures. Moreover the rate of exchange between the dollar and German Mark does not express the purchasing power in both countries.

First I want to present some figures from Mideastern Germany (Hoyer, 1957). The costs of grading spoil banks with high peaks and deep valleys, dumped by belt conveyors run between 2,500 and 8,000 DM-Ost/ha, about \$250 to \$800 per acre, much more than in Ohio. I think the high cost is partly caused by lack of adequate grading equipment at this time.

The costs of topsoil management by rail traffic are given in the same study as 20,000 DM/ha, or \$2,000 per acre. The costs for transportation of one cubic meter of topsoil, minus the cost of overburden transportation with the regular equipment, is estimated at 2.5 to 5 cents, or 2 to 4 cents per cubic yard of topsoil. Mr. Montgomery asked for the costs of reclamation of old spoil banks. If he had in mind the costs of amelioration of toxic spoil banks in the Lausitz mining district, I can give two figures. The amelioration by using brown-coal ash amounted to \$500 per acre in 1958 (Knabe, 1959b). Bruening (1962) mentions \$900 to \$1,000 per acre for a total amelioration to a depth of 20 inches.

Dr. Gaertner from the Rheinische Braunkohlenwerke left me some average figures for this area:

A. Forest reclamation:

| | DM per ha |
|-------------------------|-----------|
| Afforestation | 3-4,000 |
| Building of access ways | 2,000 |
| Grading | 1,400 |
| Total: | 6-7,000 |

(The figures divided by 10 roughly express the value in dollars per acre.)

The higher costs of afforestation, as compared with Ohio result from closer spacing, larger planting stock, and lack of State subsidies for the nurseries.

B. Agricultural reclamation:

Here we have two different areas: the northern region where the material for the loess cover can be obtained from the same mine, and the southern region where no loess is available, but has to be carried from the north for a distance of over 15 or 20 miles.

| | Northern region average DM per ha | Southern region average DM per ha |
|---|---|---|
| 1. Fixed costs | | |
| Final grading of the loess cover | 2,800 | 2,800 |
| Soil-improving farming by the coal company for 3 to 4 years | 2,000 | 2,000 |
| Building of access ways, etc. | 4,000 | 4,000 |
| Total fixed costs: | 8,800 | 8,800 |
| 2. Variable costs | | |
| Loess transportation by rail traffic | ----- | 10,000-12,000 |
| Loess transferring | ----- | 3,700 |
| First grading before spreading the loess and loosening the subsoil | ----- | 2,800 |
| Loess cover by spreading plants | 3,700 and more | |
| a) additional costs for decreased efficiency of regular equipment in Northern region | undetermined | |
| b) special units for southern region or loess cover by private operators (motor trucks) | ----- | 18,000 or 17,000 |
| Total variable costs: | 3,700 and more | about 35,000 |
| Grand total costs: | 12,500 and more | about 43,800 |

(The figures divided by 10 express about the value in dollars per acre).

We must see all these costs in relation to the value of land and the output of coal from one area. In the Rhineland good cropland can be bought at about 20-60,000 DM/ha, that is \$2,000 to \$6,000 per acre. The prices for building lots are much higher. They reach \$30,000 per acre, even in small towns, and \$160,000 per acre in big cities. Maximum prices have gone up to \$1,000,000 per acre in Munich, for instance. You see, Germany is a very densely populated country, where land has a high value. But America will reach the same density of population in the future, too. The average thickness of coal seams in the Rhineland is about 170 ft, which reduces the costs of reclamation per ton of coal. An average of forest and agricultural reclamation is supposed to amount to 0.10 to 0.20 DM or 2.5 to 5 cents per ton of coal.

But we should not look at the present costs and prices alone. I want to restate the main point. It is worth doing reclamation, even if the costs are above the present value of the land, because many generations after us will have the use of the land. Our generation has the use of the coal resource, accumulated for billions of years. I think we are not allowed to destroy this land without doing something about it for the coming generations.